3.1.3 Other Sets:

- c—5 wind classes
- l—3 wind locations (*onshore, shallow offshore, deep offshore*)
- $cCSP$—5 Concentrated Solar Power (CSP) classes
- pol—4 pollutants (SO_2, NO_x, Hg, CO_2)
- q—Conventional generating technologies:
  - hydropower
  - natural gas
    - combustion turbine
    - combined cycle
    - combined cycle with carbon capture and sequestration (CCS)
  - coal
    - traditional pulverized coal, unscrubbed, scrubbed, or cofiring
    - modern pulverized, with or without cofiring
    - integrated gasification combined cycle (IGCC) with or without CCS
  - oil-gas-steam
  - nuclear
  - dedicated biomass
  - geothermal
  - landfill gas/municipal solid waste
  - others (distributed PV)
- st—There are 4 storage technologies:
  - pumped hydropower (PHS)
  - batteries
  - compressed air energy storage (CAES)
  - ice-storage

3.2 Major Decision Variables

The major decision variables include capacity of conventionals, renewables, and storage along with transmission; and dispatch of conventional capacity and storage. Unless otherwise noted, capacity variables are expressed in megawatts and energy variables are expressed in megawatt-hours.

- $\text{Wtur}_{c,i,l}$ — new wind capacity
- $\text{WN}_{c,i,j,l}$ — new wind transmission capacity between regions
- $\text{WSurplus}_{n,m}$ — wind curtailments (surplus)
- $\text{CSPtur}_{cCSP,i}$ — new CSP capacity
- $\text{CSPN}_{cCSP,i,j}$ — new CSP transmission capacity
- $\text{ReT}_{n,p}$ — new transmission capacity for wind and CSP (renewables) between balancing areas

- $\text{CONV}_{n,q}$ — conventional capacity
- $\text{CONVgen}_{n,m,q}$ — conventional generation
- $\text{SR}_{n,m,q}$ — spinning reserve capacity
- $\text{QS}_{n,q}$ — quickstart capacity
- $\text{CONVT}_{n,p,m}$ — conventional transmission needs
- $\text{STOR}_{n,st}$ — new storage capacity
- $\text{STORin}_{n,m,st}$ — energy into storage
- $\text{STORout}_{n,m,st}$ — energy from storage
- $\text{STOR\_OR}_{n,m,st}$ — storage operating reserve capacity
- $\text{TPCAN}_{n,p}$ — new transmission capacity for dispatchable sources
- $\text{CONTRACTcap}_{n,p}$ — firm capacity contracted from another region
- RPSshortfall

3.3 Objective Function

In the objective function we minimize z where

$$
\begin{aligned}
z \quad = \quad & \sum_{c,i,l} \text{Wtur}_{c,i,l} \cdot \$capacity_l \\
+ \quad & \sum_{c,i,j,l} \text{WN}_{c,i,j,l} \cdot \$capacity_l \\
+ \quad & \sum_{cCSP,i} \text{CSPtur}_{cCSP,i} \cdot \$capacity \\
+ \quad & \sum_{cCSP,i,j} \text{CSPN}_{cCSP,i,j} \cdot \$capacity \\
+ \quad & \sum_{n,q} \text{CONV}_{n,q} \cdot \$capacity_q \\
+ \quad & \sum_{n,p} \text{TPCAN}_{n,p} \cdot \$capacity \\
+ \quad & \sum_{n,m,q} \text{CONVgen}_{n,m,q} \cdot (\$operation_q + \$fuel_q) \\
+ \quad & \sum_{n,m,q} \text{SR}_{n,m,q} \cdot \$operation_q \\
+ \quad & \sum_{n,q} \text{QS}_{n,q} \cdot \$capacity_q \\
+ \quad & \sum_{n,st} \text{STOR}_{n,st} \cdot \$capacity_{st} \\
+ \quad & \sum_{n,m,st} \text{STORout}_{n,m,st} \cdot (\$operation_{st} + \$fuel_{st}) \\
+ \quad & \sum_{n,m,q} \text{CONVgen}_{n,m,q} \cdot \$pollution_q \\
+ \quad & \text{RPSshortfall} \cdot \$penalty
\end{aligned}
$$